HYGROTHERMAL PERFORMANCE ANALYSIS OF TRADITIONAL TIMBER-FRAMED HOUSES IN TURKEY

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ABSTRACT

The study aims to analyse hygrothermal performance of traditional timber-framed houses in order to discuss building skins' energy efficiency. There are numerous types of traditional timber-framed houses in Anatolia depending on social, cultural and regional features. Within the scope of this paper, the traditional architectural features of Safranbolu County of Turkey is selected as the case study. Safranbolu is placed in the Western Black Sea region, where specific examples of traditional timber-framed constructions with adobe infill are housed. As a significant example, "hımış" is a hybrid construction of stone masonry walls on ground level, and infilled timber-frame walls in upper levels. The construction of hımış is organized by rectangular studs of pinewood, and infill material of adobe. Wooden diagonals, which cope with the dynamic loads, especially earthquake, support the system and provide long-term durability for these buildings. In this study, hımış construction wall type with adobe infill is selected. The selected example is simulated by Delphine 6.0 for the evaluation of hygrothermal performance. Considering energy efficiency, hygrothermal performance is investigated by heat transfer and moisture control in order to raise awareness of traditional timber-framed capacities. The main purpose to focus on hygrothermal performance analysis is to integrate indigenous knowledge into contemporary architecture regarding social, economic and cultural characteristics in a sustainable manner. The expected outcome of this study is the determination of the selected type of traditional timber-framed buildings' hygrothermal performance.
Keywords: hygrothermal performance, traditional timber-framed buildings, Delphin 6.0, adobe infill.

1 INTRODUCTION

Since the cities have been transformed by the effects of the Industrial Revolution, minimizing energy consumption has been prioritized. Urban settlements consume nearly 80% of global energy and 40% of it is used by buildings [1]. During the building construction and operation processes, 50% of produced energy and 42% of water is used in the world. In Europe, the construction sector consumes 40% of produced energy and 30% of CO_2 emission [2]. Due to energy usage and CO_2 emissions increasing expeditiously, energy efficiency has been one of the most critical discussion topics in all around the world.

There are numbers of national and international action, sustainability certificates programs, committees, standards and codes that aim to find ways to save the world from the all negative effects of energy consumption. Sustainable Development Goals is one of a universal call to act for ending poverty, protect the world and improve the lives of everyone in everywhere. In 2015, 17 Goals were determined and adopted by all UN Member States as 15 years plan for the 2030 Agenda of Sustainable Development. Affordable and clean energy, sustainable cities and communities, climate action are the main topics that decelerate to supply affordable, reliable, sustainable and modern energy for everyone [3].

As an international standard, EN ISO 13788: 2012, Hygrothermal performance of building components and building elements – Internal surface temperature to avoid critical surface humidity and interstitial condensation – Calculation methods, is the main source for hygrothermal performance analysis. In the scope of this study, this standard is applied to

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investigate the hygrothermal performance analysis. Moreover, the simulation tool Delphin 6.0, which is used for the modelling of the case study, is based on DIN EN 13788. This standard is the German version of EN ISO 13788: 2012 and it is referenced in the simulation process of the model [4]. This standard indicates calculation methods and risks of condensation problems depending on temperature and relative humidity considering the indoor and outdoor climatic conditions. In 2004, TS EN ISO 13788, as the Turkish version of EN ISO 13788 is came into force.

In Turkey, especially legal authorities have worked on sustainability since the end of the 1990s. "TS 825-Thermal Insulation Requirements for Buildings" is a first national standard that determines the criteria for improvements of building energy performance. In Turkey, it is aimed to 20% energy saving by the improvements of the existing buildings' energy performance [5]. The results of analysis on buildings' CO_2 emissions in Turkey shows that 12% of the energy is consumed for manufacturing of building materials, 1% for construction, 83% for operation, 3% for maintenance and 1% for others [6]. Most of the researches about energy efficiency show that heating and cooling consume most of the produced energy in the world. In 2009, the report of the Chamber of Mechanical Engineers in Turkey, declares that 75% of produced energy is consumed for heating in buildings [7]. In order to minimizing energy usage for heating and cooling, applying thermal insulation to buildings may be a criterion for energy efficiency [8].

Other than that, there are two significant ways for energy efficiency for buildings; new green buildings and renovating the existing ones [9]. Even if most of the existing buildings have not responded the hygrothermal performance criteria, it is essential to develop their hygrothermal performance in order to minimize thermal and moisture control problems [10].

Traditional buildings are the specific issue for energy efficiency of existing buildings regarding their historical, cultural, social and architectural values. In the literature, there is an extensive source about documentation; conservation and preservation of traditional buildings are fundamental working area for years. Even if there are several researches about the energy performance and energy efficiency of the traditional buildings in Italy, Sweden etc., the researches about the energy performance and energy efficiency of the traditional buildings in Turkey still have not been worked on in detailed.

This study aims to investigate hygrothermal performance of traditional timber-framed buildings' skin by using simulation tool, Delphin 6.0. Within the scope of the study, Safranbolu is selected for case study as a specific district where the significant example of traditional timber framed with adobe infill system is placed.

1.1 Method

The paper presents as a part of an ongoing study. The study based on both qualitative and mainly quantitative research techniques and methods. The research starts with a comprehensive literature review about traditional timber-framed building in Turkey. Then, for this part of the study, one of the significant examples of traditional timber-framed buildings in Turkey, timber framed with adobe infill is selected for the case study. This type of construction is mostly housed in Safranbolu County of Turkey. Therefore, the case study part starts with the findings on the selected area and the selected type of construction. In the second part of the paper, quantitative methods are adopted. For hygrothermal performance analysis of the selected type, the Delphin 6.0 programme is applied as hygrothermal performance simulation tools. This part of the simulation is focused on the hygrothermal performance between timber-framed and adobe infill. It is analysed 20 cm × 21 cm part of the selected wall.

1.2 Objectives

This paper shows the results of first part of a comprehensive research about the traditional timber-framed houses' hygrothermal performance. The comprehensive research aims to propose a contemporary timber framed wall type(s) for Turkey regarding the national requirements and characteristics. While designing the proposed timber-framed wall type(s), contemporary timber materials and construction systems such as cross laminated and/or glulam laminated panels, are not applied. The focus point of the comprehensive research is to improve the hygrothermal performances of traditional timber-framed houses in Turkey considering the contemporary architectural approaches. In order to improve a new timber-framed wall type(s) for Turkey as a contemporary example, it is crucial to examine the hygrothermal performances of traditional timber frame examples in Turkey. Therefore, in the first step, hygrothermal performances of the traditional timber-framed examples in Turkey are analysed by simulation programme Delphin 6.0.

The reasons of why this programme is selected for simulation are expressed elaborately in the following. In Turkey, there are several types' examples of traditional timber-framed houses. And these types will be analysed within the scope of the comprehensive research. However, in this part of this research, one of the most used types of examples which are mainly located in Safranbolu is selected for hygrothermal performance analysis by simulation program, Delphin 6.0. It is expected that this part of the research provides some preliminary results for planning the ongoing comprehensive research.

2 HYGROTHERMAL PERFORMANCE

Considering energy efficiency of buildings, thermal performance may not be only criterion for improvement of energy performance of buildings. Herein, heat and moisture are the two major factors that are directly related with energy efficiency of buildings. In order to examine the effects of heat and moisture factors for energy efficiency, hygrothermal performance plays critical role. Hygrothermal performance means analysis of construction materials by assessments of energy, moisture and air balances. The hygrothermal performance examines the heat flows by conduction, convection, and radiation; moisture flows by vapour diffusion, convection, and liquid transport; and airflows caused by natural, external or mechanical forces [11].

There are three major sources including criteria for hygrothermal performance analysis; the first source is prepared by WTA in 2002 covering the conservation and renovation of heritage buildings and existing constructions, the other one is European Standard EN 15026 (2007) regarding mostly WTA source published before and third one is the American Standard (ANSI/ASHRAE Standard 160 2009).

Moreover, hygrothermal performance is an important issue for building pathology. Moisture is one of the significant factors for damages of building components. In addition to that, moisture has impacts on users' health and comfort conditions. Even if moisture-based pathologies are difficult to manage, the knowledge of building system and/or buildings' hygrothermal behaviour is available with innovative technics on physical processes of materials [12].

In the beginnings, moisture control analysis was based on "Glaser-calculations" that determines condensation risk in the building components through heating season. Nevertheless, this calculation method does not consider the long-term process. Therefore, it is required to be applied a new method that consists of detailed calculation method for the whole processes [13].

2.1 The role of simulation programs for hygrothermal performance analysis

There are several hygrothermal simulation tools and numbers of studies about credibility of these simulation tools in the literature. In 2007, the research about hygrothermal simulation tools indicates that there are 57 simulation tools about hygrothermal performance analysis of building components [14]. Most of these tools are capable to analyse moisture content, temperature and relative humidity by modelling physical process of transportation implying simplification of given detailed about reality.

Due to the experimental research method applied for hygrothermal performance analysis has some difficulties, hygrothermal performance simulation tools are mainly used in the literature. The early studies about these simulation tools are based on reliability and creditability of the hygrothermal simulation tools by comparing the experimental studies and the simulated models. Meanwhile, most of these simulation programs are proved their capacity of applicability for building components' hygrothermal performance analysis.

The inputs for hygrothermal performance simulation tools are (1) geometry of enclosure, (2) boundary conditions (interior, exterior and indoor and outdoor surface transfer), (3) material properties (bulk density, porosity, specific heat capacity, thermal conductivity, water vapour permeability, water absorption coefficient, moisture storage functions, and reference values [11].

1D-HAM, BSim, Delphin, EMPTIED, GLASTA, HygIRC, HAMLab, HAM-Tools, IDA-ICE 4.5, MATCH, MOIST 3.0, MOISTURE EXPERT, UMIDUS, WUFI are one of the selected hygrothermal performance simulation tools in the literature. WUFI is one of the most commonly used hygrothermal simulation tools. It is a 1D simulation programme that is capable to make model of hygrothermal performance of porous materials. The archived weather data is applied for to in-situ conditions simulations. WUFI consists of a comprehensive library of materials and weather data from around the world [15]. To compare these simulation tools with each other, there are some difference about the capability and content of each simulation programs. Therefore, it is crucial to analyse the simulation programme context before applying. Within the scope of this research, Delphin 6.0 is applied to investigate the hygrothermal performance of the selected example.

Delphin is a commercial hygrothermal performance simulation tool analysing heat and moisture flows through building materials and components by 1D or 2D modelling. This simulation programme is applicable for calculation of thermal bridges, analysis of hygrothermal problems and examining insulation proposals for building components. The programme has a capacity to test various types of indoor and outdoor climatic conditions [16].

The majority of the hygrothermal performance simulation programs disregarded the multi-layered conditions of the interiors, while concentrating on the outdoor spaces' climatic conditions. In terms of probabilistic approach for hygrothermal analysis, Delphin, the hygrothermal performance simulation tool, gives opportunities to examine the parameters of temperature and relative humidity for building components during the processes [17].

2.2 Hygrothermal performance in traditional buildings

Currently, energy performance of heritage buildings has been a crucial research area for both researchers and practitioners [18]. In Venice Charter, it is specified that conservation of a monument should consider facilities by making use of this monument [19]. One of the efficient ways to preserve the traditional buildings is to provide user comfort conditions in

current usage and/or propose a function for adaptive reuse. Thus, it may be a proper solution to develop energy efficiency of the traditional buildings. This proposal also contributes the sustainability of cultural, architectural and historic values of traditional buildings by handing them down to the next generations. Traditional buildings have been inseparable components of cultural heritage that supply social, cultural and architectural sustainability in terms of varieties in different locations [20].

Even if protecting the historical values of the traditional buildings, it is an obligation to improve the energy efficiency of the existing buildings [21]. Before proposing an idea about hygrothermal performance improvement for a traditional building, it is necessary to have a data about the construction methods and the material behaviour under the different temperature and moisture conditions depending on the climatic conditions of the location. Especially for timber-framed buildings, to improve energy efficiency it is essential to investigate the hygrothermal performance of the proposal regarding to construction physics while conserving the historical value [22].

Turkey has selected agenda of traditional buildings consist of different construction material and technics. Timber-framed constructions are one of the unique types of traditional buildings in Turkey. Considering them as the significant part of the cultural heritage, preservation of them is crucial for sustainability of cultural heritage [23].

There is a vast literature about traditional buildings in Turkey. Most of them are focused on documentation, conservation and restoration. These researches provide extensive resource for the literature. Nevertheless, energy performance and energy efficiency of the traditional buildings are not specifically examined. This study concentrates on hygrothermal performance of traditional timber-framed buildings in Turkey. The goal is to examine the hygrothermal performance of the selected examples and design proposal for developments of energy efficiency.

3 CASE STUDY

Regarding the traditional architecture in Turkey, wood is the basic construction material throughout years. Most of the studies point out that after Turks adopted settled life in Anatolia; they have developed their wooden material and construction technics in years. As a construction material, wood has opportunity to easily use and apply. It is seen that traditional architecture in Turkey is based on these opportunities in a composition of uniqueness. The traditional architecture in Turkey, especially traditional houses are one of the selected types of timber-framed systems. Most of the timber-framed systems are constructed with infill materials such stone, adobe and brick infill according to the geographical, social, cultural and local conditions. Since the infill materials are varied depending on regional factors, timber-framed system is the basic construction type in Turkey [24]. Timber-framed traditional buildings in Turkey may be classified in four groups in terms of material usage: timber framed – airgap, timber framed – adobe infill, timber framed – brick infill and timber framed – stone infill. The infill material is changed depending on climate, topography, culture and economy [25].

There are seven different geographical regions in Turkey: Marmara, Aegean, Mediterranean, Central Anatolia, South-eastern Anatolia, Eastern Anatolia, and Black Sea. Each of these districts has its significant social, cultural, geographical, economic and architectural characteristic. Within the scope of this paper, the traditional architectural features of Safranbolu County of Turkey, is selected as the case study. Safranbolu is placed in Western Black Sea region where specific examples of traditional timber framed with adobe infill constructions are housed. As a significant example “hımış” is a hybrid construction of stone masonry walls on ground level, and infilled timber frame walls in

upper levels. The construction of hımış is organized by rectangular studs of pinewood, and infill material of adobe. Wooden diagonals, which cope with the dynamic loads especially earthquake, support the system and provide long-term durability for these buildings. In this study, hımış construction wall type with adobe infill is selected. In this step, the hygrothermal performance of infill part of the wall is examined. The 20 cm × 21 cm part of the wall where timber-framed and adbobe infill intersect with each other is simulated. Fig. 1 shows an example of hımış in Safranbolu. Fig. 2 presents the layers of the selected example.

Figure 1: A picture of hımış example in Safranbolu *(Source: https://pixabay.com)*.

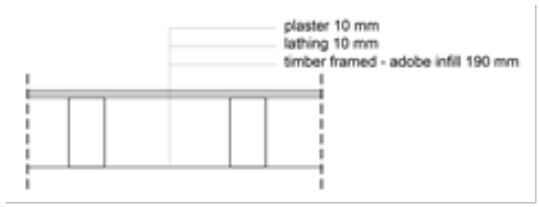


Figure 2: The layers of skin (illustrated by Seda Nur Alkan).

The selected example is simulated by Delphine 6.0 for the evaluation of hygrothermal performance. The weather data for outside condition is supplied by programme in TRY format. The interior condition is arranged according to DIN EN 13788; indoor temperature is 20°C and relative humidity is 50% for the simulation process. The simulation tool presents data about temperature and relative humidity for thermal performance analysis. The weather data of Karabük, where Safranbolu is located as a district is used for the simulation. The simulation started on January 1, 2007 and finished on January 1, 2008. According to the simulation, the temperature and relative humidity values are shown in Fig. 3. The highest value of relative humidity is seen in the winter season, when the temperature is under 0°C. It is observed that the relative humidity is getting closer to 100% during the cool season, while it is closed 30% in the warmest season.

The vapor pressure relationship with temperature and relative humidity are critical to analyse the hygrothermal performance of building components. As it is seen in Fig. 4, the vapor pressure directly related with temperature difference. It is observed that the differences between vapor pressure in a year are increased parallel to each other. It may create moisture-based problems in the wall.

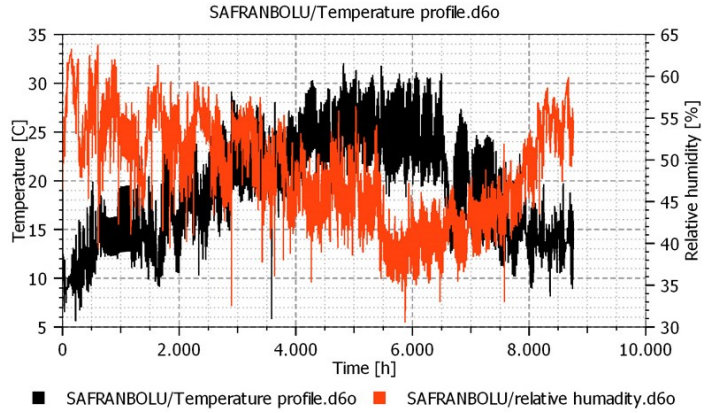
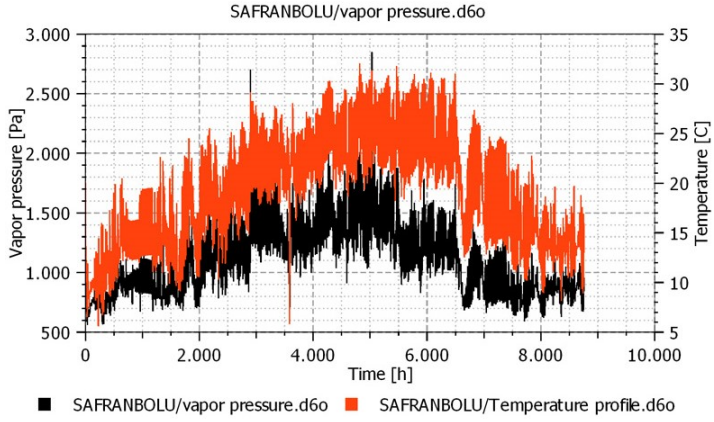
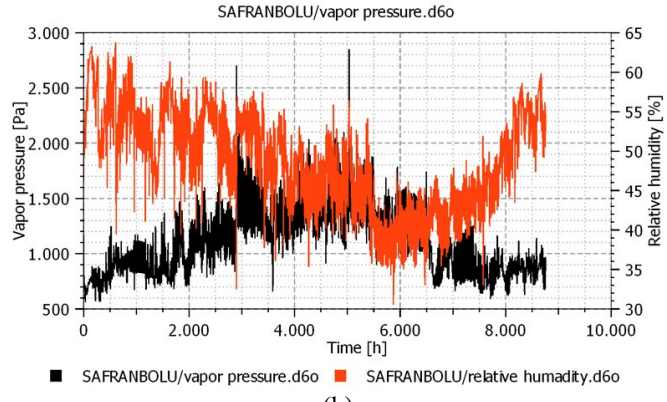


Figure 3: The temperature and relative humidity values during a year.



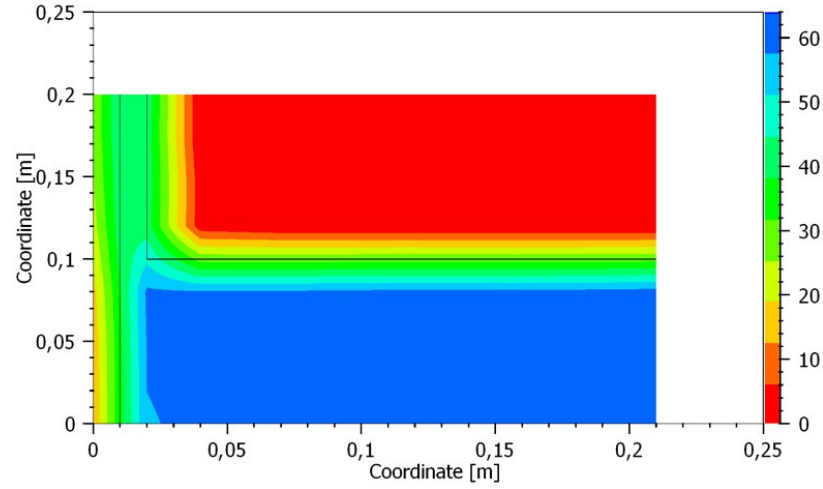
(a)



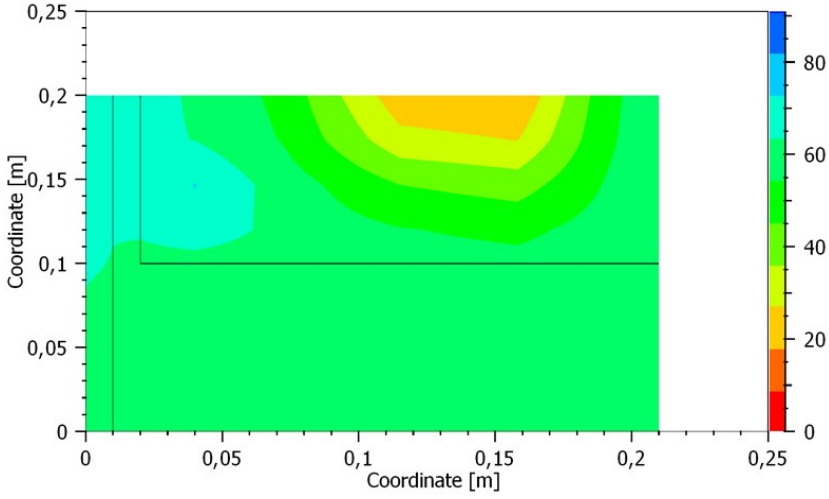
(b)

Figure 4: (a) The vapor pressure and temperature relation values during the year; (b) The vapor pressure and relative humidity relation during the year.

The simulation programme supply 4D representation of total mass density of liquid water, water vapor and ice during the year (Fig. 5(a)) and the relative humidity in the mass during the year (Fig. 5(b)). By analysing these graphics, it is possible to understand condensation problems in the building components. Also, the moisture flows in the mass is represented in detailed. It may say that the connection points of timber framed with adobe infill are critical for condensation problems. In the long term, this situation may cause deformation on timber-framed structure in terms of durability, chemical and physical deterioration. Therefore, it has been an obligatory to solve the condensation problems for improving hygrothermal performance of the building skin.



(a)



(b)

Figure 5: (a) The total mass density of liquid water, water vapor and ice during the year; (b) The relative humidity in the mass during the year.

Considering energy efficiency, hygrothermal performance is investigated by heat transfer and moisture control in order to raise awareness of traditional timber-framed capacities. The main purpose to focus on hygrothermal performance analysis is to integrate indigenous knowledge into contemporary architecture regarding social, economic and cultural characteristics in a sustainable manner. The expected outcome of this study is the determination of the selected type of traditional timber-framed buildings' hygrothermal performance.

4 CONCLUDING REMARKS

Regarding the energy efficiency as a critical issue for all over the world, hygrothermal performance of the buildings have been started to discuss in detailed in addition to thermal performance of the building skins. Most of the researches started to consider moisture while analysing the temperature values for building components.

Since the new buildings have been focused issue for hygrothermal performance analysis, the existing buildings have been also fundamental to consider. Herein, traditional buildings have significant role in terms of their social, cultural, historical and architectural characteristics. Therefore, it is important to evaluate their hygrothermal performance while conserving their uniqueness.

Many of the studies in Turkey have worked on documentation, renovation and restoration of the traditional buildings. Even though some researches have been started to focus on sustainable design proposals for traditional buildings, mainly performance analysis are not investigated sustainability in terms of hygrothermal performance. Therefore, energy efficiency of the traditional buildings is not widely discussed.

The aim of this study is to make research about hygrothermal performance of traditional timber-framed buildings' skin by using simulation tool, Delphin 6.0. Within the scope of the study, Safranbolu is selected for case study as a specific district where the significant example of traditional timber framed with adobe infill system is placed. According to the simulation results, hygrothermal performance is analysed considering the heat flows by temperature data and moisture flows by relative humidity and vapor pressure. It is seen that due to the hygrothermal performance analysis requires comprehensive analysis and research processes, this study aims to be continued with further studies concentrating hygrothermal performance simulation tools and experimental studies.

The expected outcome of this study is to open a discussion about hygrothermal performance of traditional timber-framed buildings considering them as architectural heritage in terms of cultural, historical and social features. This attempt may contribute to sustainability of cultural, social, architectural and historic values of traditional buildings.

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